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Future Trends in Aircraft Design

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IN DISCUSSING FUTURE AIRCRAFT design trends in view of the current economic environment, one is tempted to be pessimistic. The airlines appear to be overcommitted, and the general economic well-being of the industry is not good. However, past experience tells us that the airplane business is and always has been cyclic. There is no reason to suspect that positive air traffic growth, as experienced during the sixties, will not return in the future. When it does, a large, unfilled lift requirement should develop in several market areas. To satisfy these new market requirements, several possible products, including derivatives of the current airplanes as well as "all new" designs, will be needed. In addition to the basic mission requirements, environmental considerations such as noise and airport congestion will impose specific technology challenges for each new product.

This paper reviews the projected traffic forecast, comments on the application of current programs and their derivatives to the future unfilled market areas, and identifies some possible new programs that could be applied to new market opportunities. Airplane designs for these new market areas are described and some of the associated technology challenges for each are discussed.

THE MARKET

Before future design trends can be discussed, the market potential, which is the real driving force for new trends, should be examined. Air transportation has been steadily growing since its inception because it has offered the traveler greater comfort and shorter trip times at acceptable costs. This trend is illustrated in Figure 1. Notice the substantial swell that took place starting about 1963. The effects of speed, comfort, and fares provided by the new jet transports of that era are quite evident.

Figure 2 shows the distribution of traffic between U.S. and foreign airlines and also forecasts the expected demand to 1985. The decline in rate of traffic growth for the years 1968 through 1971 were caused primarily by the recession in the United States. The non-U.S., or overseas, airlines have enjoyed sustained growth, while the U.S. airlines have been experiencing reduced growth during most of the past 3 years.

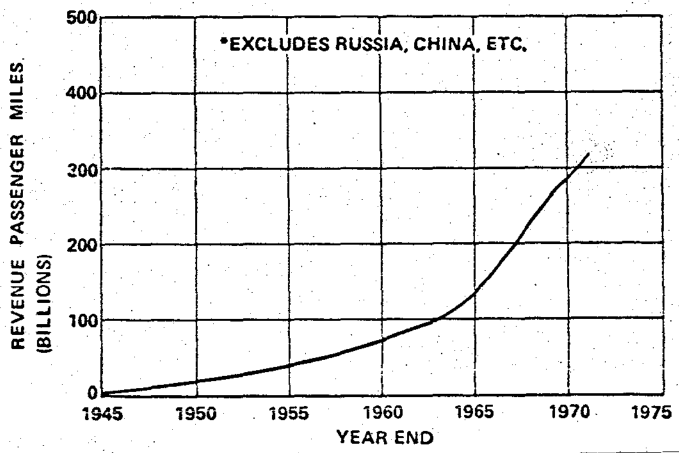


FIGURE 1. TOTAL WORLD AIR TRAVEL*

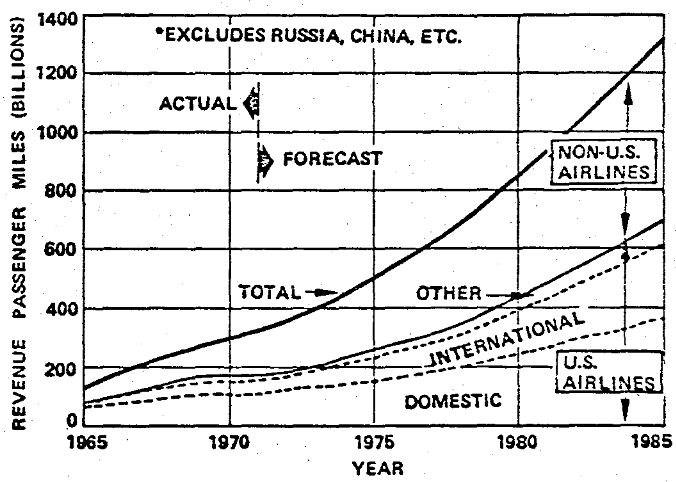


FIGURE 2. WORLD AIR TRAVEL FORECAST*

Market forecasters consider this slump to be only temporary and predict an encouraging future. They expect the demand for air travel to continue to grow over the long term so that during the next 10 years it should nearly triple its current level. If this prediction turns out to be only partially accurate, there is still ample future market potential available to delight the airplane designer. Let's hope so and plan for it.

There are many good airplanes in airline service today (approximately 4200) and more about to be delivered, as shown in Figure 3. The 747's (over 200) and the DC-10's, which have just entered service, will certainly provide a tremendous lift capability during the next few years.

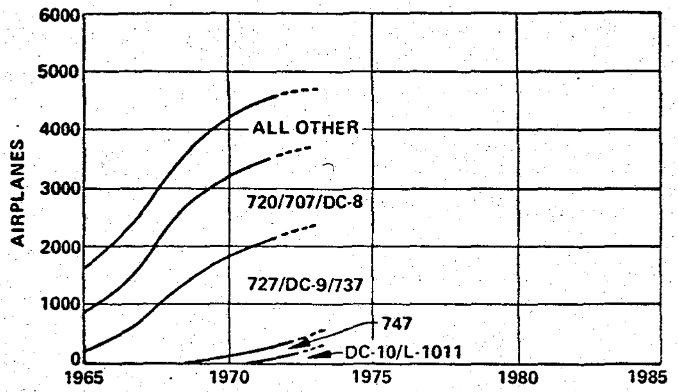


FIGURE 3. AIRPLANES IN SERVICE AND ON ORDER

By assuming a 55% load factor and considering typical airplane seating capacity and route application, the effect of these existing and on-order airplanes in filling the lift requirements of Figure 2 can be shown (Fig. 4). As we well know, there is no shortage of lift available now. In fact, there appears to be ample lift available on an overall basis until the end of 1974, assuming no retirements.

The foregoing conclusion would assume that the distribution of airplanes is just right for the available market, which is not true. Some airlines are still buying while others have a surplus. The desire to retire some of the older and less desirable airplanes can have a substantial effect on the unfilled requirement as shown in Figure 4. It is apparent that the unfilled market requirement is highly dependent on sustained traffic growth and some reasonable rate of retirement. Improvements in current airplanes and new designs could have a large influence on both factors.

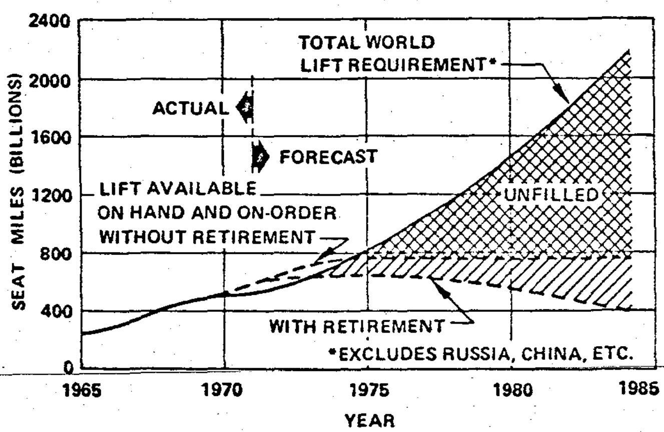


FIGURE 4. UNFILLED LIFT REQUIREMENTS

COMMITTED PROGRAMS

A very significant part of future trends in airplane design is associated with the extended application of current designs. Considering the tremendous investments that have been made by the air transportation industry, airlines, and manufacturers, it must be evident that continuation of existing programs with modest improvements and at moderate cost will constitute the main thrust in the near term. To illustrate this point, the design payload-range capability of most of the current airplanes is shown in Figure 5. Considering that all these models can operate satisfactorily over shorter ranges than their design ranges, it would seem that the available supply is ample to cover the field. However, such a static situation has not been typical of the past, and the industry may not have flourished as it did in the sixties if model improvements and new designs had not been introduced. On the other hand, the economic experience of the past few years causes most of the industry to be cautious.

The designer, although he may worry a great deal over the validity of future predictions, knows that many options or alternatives must be examined and be available from which future courses of action can be chosen.

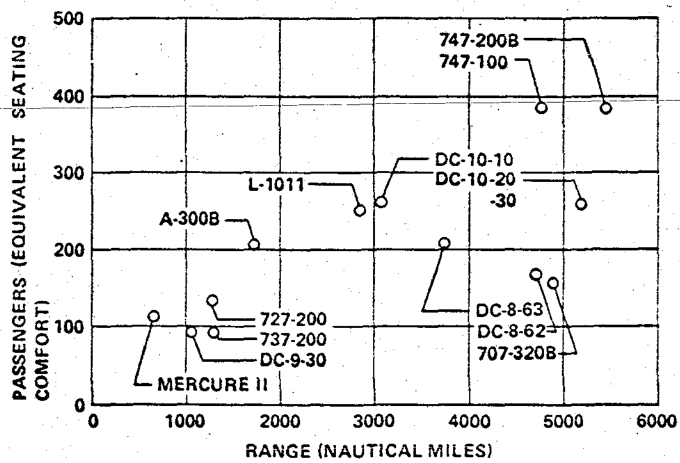


FIGURE 5. PAYLOAD-RANGE CHARACTERISTICS

EXTENSIONS OF CURRENT PROGRAMS

Looking first to the published information on competitive airplanes, several growth versions have been examined as illustrated in Figure 6. From the basic DC-10 design has evolved the long-range DC-10-20 and DC-10-30 versions, both of which are committed to future production. In addition, McDonnell-Douglas has shown potential designs that increase payload through body extension and also some that reduce payload-range through body reduction and removal of the center engine with attendant reductions in gross weight.

These approaches are aimed at extending the capability of their product to more fully satisfy market requirements while limiting the investment requirements. Two growth versions of the A-300 were selected from published data to show that the A-300 designers also are considering major changes even before the first airplane has flown.

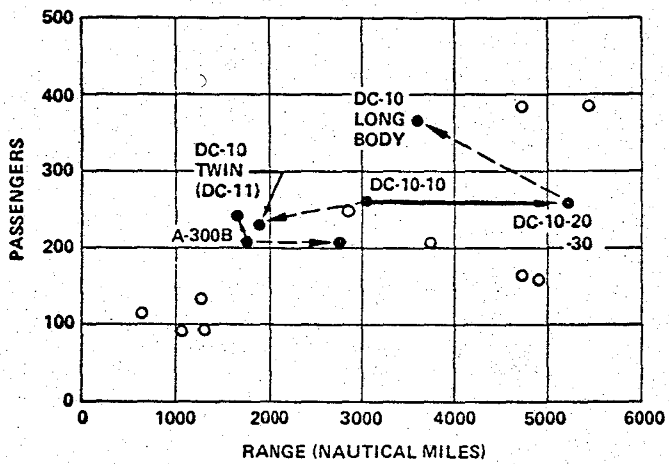


FIGURE 6. SOME GROWTH POSSIBILITIES OF COMPETITIVE AIRCRAFT

In the case of Boeing, growth versions of all models are also constantly under investigation. To illustrate the effect of broader application of a particular model to additional market requirements, some of the 747 potential growth possibilities are shown in Figure 7.

Originally, the 747 was designed to carry approximately 370 passengers about 4700 nautical miles with a substantial amount of cargo in the lower holds. The first growth-version 747-200B has already been delivered and is now in service. It was designed to fly approximately 700 nautical miles further than the original 747-100.

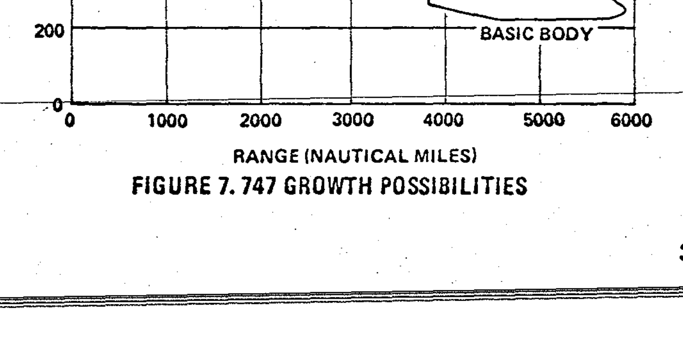


FIGURE 7. 747 GROWTH POSSIBILITIES

The 747-SR (short range) is another version that develops from the basic 747-100 and is intended to be used for short-range commuter-type service. It features high-density seating and special design characteristics aimed at short flights involving many takeoffs and landings. Rapid turn-around, snappy and quiet takeoff performance, short landing field lengths, and advanced structural concepts for improved fatigue life to accommodate a very difficult duty cycle are all features offered in the 747-SR.

Other growth possibilities of the 747 that involve increased payload are also shown in Figure 7. The upper deck behind the pilot's compartment has developed into a very attractive area. It has already been extended somewhat and could be extended substantially more. Wind tunnel tests have demonstrated that improvements in critical Mach number result from these upper deck extensions because the cross-sectional area distribution of the airplane is improved for flight Mach numbers approaching 0.9. Body extensions could also substantially increase passenger capacity; and, if required, the upper deck could even be extended to the full length of the fuselage.

Considering the current congestion at terminal areas involving long delays, both on the ground and in the air, these types of changes could be very alleviating. A big 747 takes essentially no more air space, runway space, taxi space, and only moderately greater terminal gate space than a 737 or 727. In heavily populated areas, large passenger loads in a single vehicle could represent the only reasonable means of handling the ever-increasing number of travelers.

The foregoing discussion could apply equally to smaller airplanes and communities but on a smaller scale. Growth versions of the 727, 737, DC-9, and others will be similarly explored and improvements offered since the competition is just as significant in these market areas.

These kinds of improvements, which build on the existing base of airplanes, will dominate the design trends in the near term. As was noted in Figure 5, the existing base is large, modern, and useful. Economic considerations dictate that this potential be fully exploited before major new investments are incurred.

NEW TECHNOLOGY

In addition to a positive market requirement, advanced technology is a prerequisite for any successful new program. The increase in aircraft speed, capacity, range, reliability, and safety that has characterized air transportation growth and the wide public acceptance of the resulting service is a direct result of improved technology. A great deal of progress continues to be made. This progress plus some possible future developments that could contribute to a new airplane program are discussed below.

PROPULSION—Engine technology, as usual, will play a major role in any new product. The three high-bypass-ratio turbofan engines on the new-generation jet transports—the Pratt & Whitney JT9D, the General Electric CF6, and the

Rolls-Royce RB211—offer a number of important improvements. Compared to the earlier low-bypass-ratio engines, these designs decrease specific fuel consumption significantly, offer a lower weight per unit of thrust, and lower noise levels.

Future developments will incorporate additional quiet-engine technology and engine emission reduction. Areas of emphasis will include quiet-fan design, jet-noise reduction, and structural cowls incorporating load carrying acoustical materials.

AERODYNAMICS—Recent developments in supercritical flow technology and augmented high lift show significant aerodynamic advances for application to new products. Supercritical flow technology combines two major elements, supercritical airfoil and refined area ruling techniques. This technology will allow efficient flight near Mach 1.0 or increased wing thickness at design speed similar to current jetliners. Supercritical flow applications are currently being demonstrated on two NASA flight test programs. Tests of a modified T2C straight-wing trainer, cosponsored with the U.S. Navy, have demonstrated that an increase of 40% in wing thickness can be achieved at no reduction in speed capability. Tests of an F8 with a highly swept supercritical wing design are in progress to provide full-scale verification of the very favorable wind tunnel results near Mach 1.0. The high-speed performance improvement possible with the application of supercritical airfoil and refined area ruling techniques is illustrated in Figure 8. With only 5° more wing sweep and a relative thickness distribution very similar to that of the 747 wing, the drag divergence has been increased by approximately 0.10M.

Substantial gains in high-lift technology are available through improved mechanical flap efficiency and various blowing augmentation schemes. Cambered leading-edge devices, such as those installed on the 747, and continuous-span trailing edge flaps with clean slots offer modest

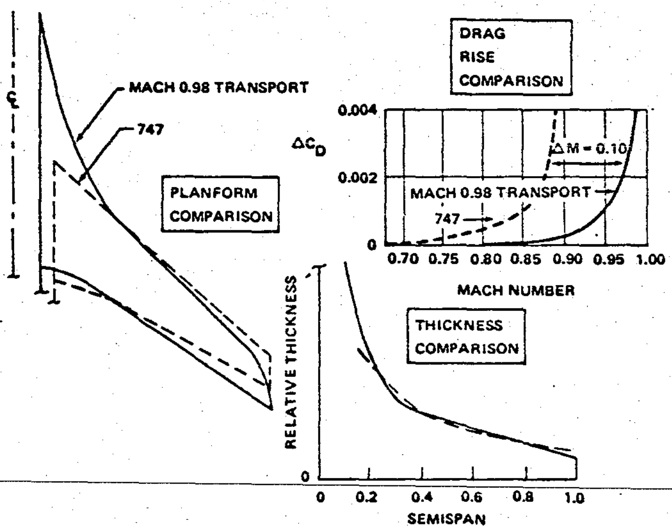


FIGURE 8. ADVANCED AERODYNAMIC TECHNOLOGY

improvements. For short takeoff and landing applications, augmentation through the use of engine air is available to provide high circulation lift. To be able to use highly augmented lift and high thrust settings during landing, cross ducting, increased flap drive rates, and improved lateral control systems are required.

The emphasis on noise reduction will also impact flap design. For conventional airplanes, low flap settings can be used to reduce takeoff and approach noise. For STOL airplanes requiring very high lift and large flap settings, schemes such as the augmentor flap, which can be treated acoustically, offer potential for noise reduction.

STRUCTURES—Two advanced structure technologies—composites and bonding—could provide a significant breakthrough in lower aircraft weight, improved structural durability and life, and reduced in-service maintenance costs. Advanced fiberous composite materials using boron or graphite filaments achieve higher specific strength and stiffness than the metallic materials currently employed for commercial construction. Future aircraft designs could incorporate various levels of composite structure, depending on structural technology advancement. Initially, composite materials could be employed in unidirectional form to carry axial loads only (examples: wing and body stiffeners and struts). Next, shear-carrying metal could be replaced by fibers oriented diagonally (examples: wing and body skins). The all-composite airplane, representing the ultimate in fiberous composite technology, would orient the fibers to simultaneously resist axial and shear loads in the most efficient manner.

The airframe areas identifiable as candidates for bonded structure are the fuselage and wing—adhesive-bonded aluminum honeycomb sandwich construction for the fuselage and bonded skin-stringer construction for the wing. In addition to lighter structure, both would provide improved fatigue performance.

Titanium and steel structures as well as graphite brake material could also be used to reduce weight.

FLIGHT CONTROLS—Flight research has resulted in significant advances in the state of the art of flight control technology. These include such areas as stability augmentation, maneuver load alleviation, gust load reduction, and approach path control.

Designs with relaxed inherent stability, using aft center-of-gravity positions, will show improvements in configuration efficiency through reduced structural weight and improved cruise performance because of lower trim loads. Load alleviation devices such as outboard aileron deflectors can also reduce both gust and maneuvering loads to further reduce weight, improve ride qualities, and extend fatigue life.

Improved airplane control and guidance in terminal areas will be available through incorporation of automatic flight-path control, advanced flight deck displays, and three-dimensional guidance. These systems will allow optimum climb performance on takeoff and steeper glide slope, decelerating approaches on landing. The automation of these functions also will relieve pilot workload, permit increased traffic capacity, and, through revised operational techniques, reduce community noise.

NEW PROGRAMS

The foregoing technology can be applied to future airplanes and to improved versions of existing airplanes. With improved technology, many new designs are possible. However, only two potential applications–long range and STOL–are discussed in this paper. The market areas for these applications are shown in Figure 9.

LONG-RANGE TRANSPORT–For the long-range market, two designs are examined: a new technology Mach 0.84 airplane and a near-sonic Mach 0.98 airplane. Artists concepts of these candidate configurations are presented in Figures 10 and 11.

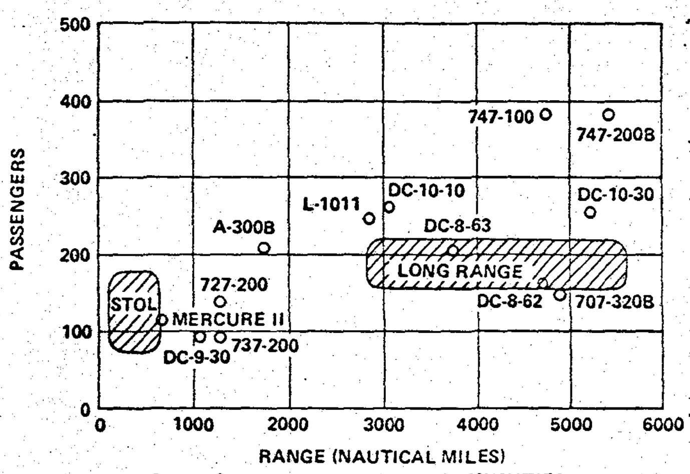


FIGURE 9. NEW PRODUCT OPPORTUNITIES

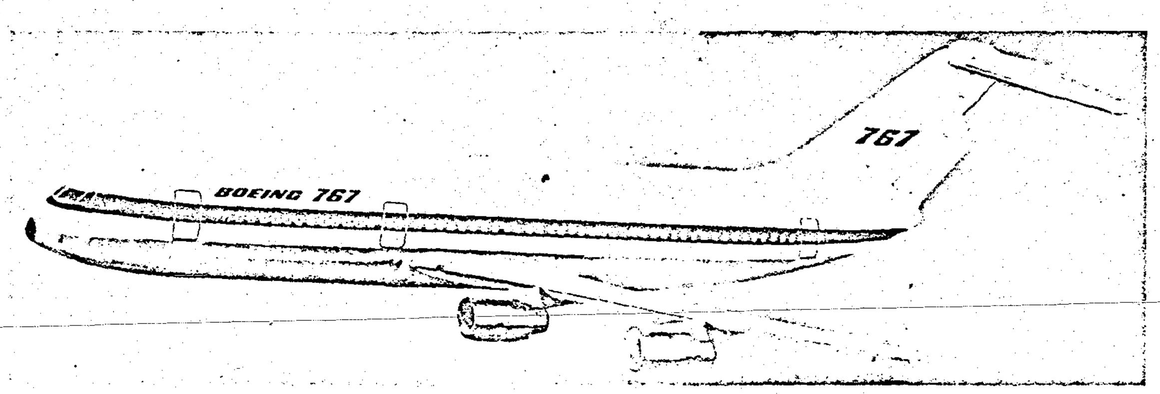


FIGURE 10. MACH 0.84 TRANSPORT

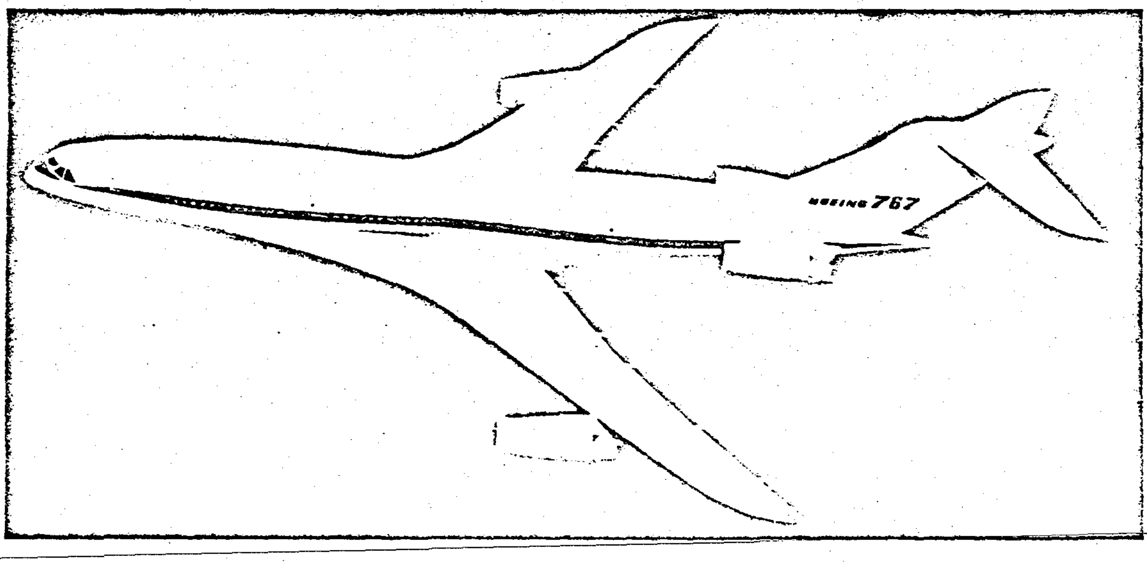


FIGURE 11. MACH 0.98 TRANSPORT

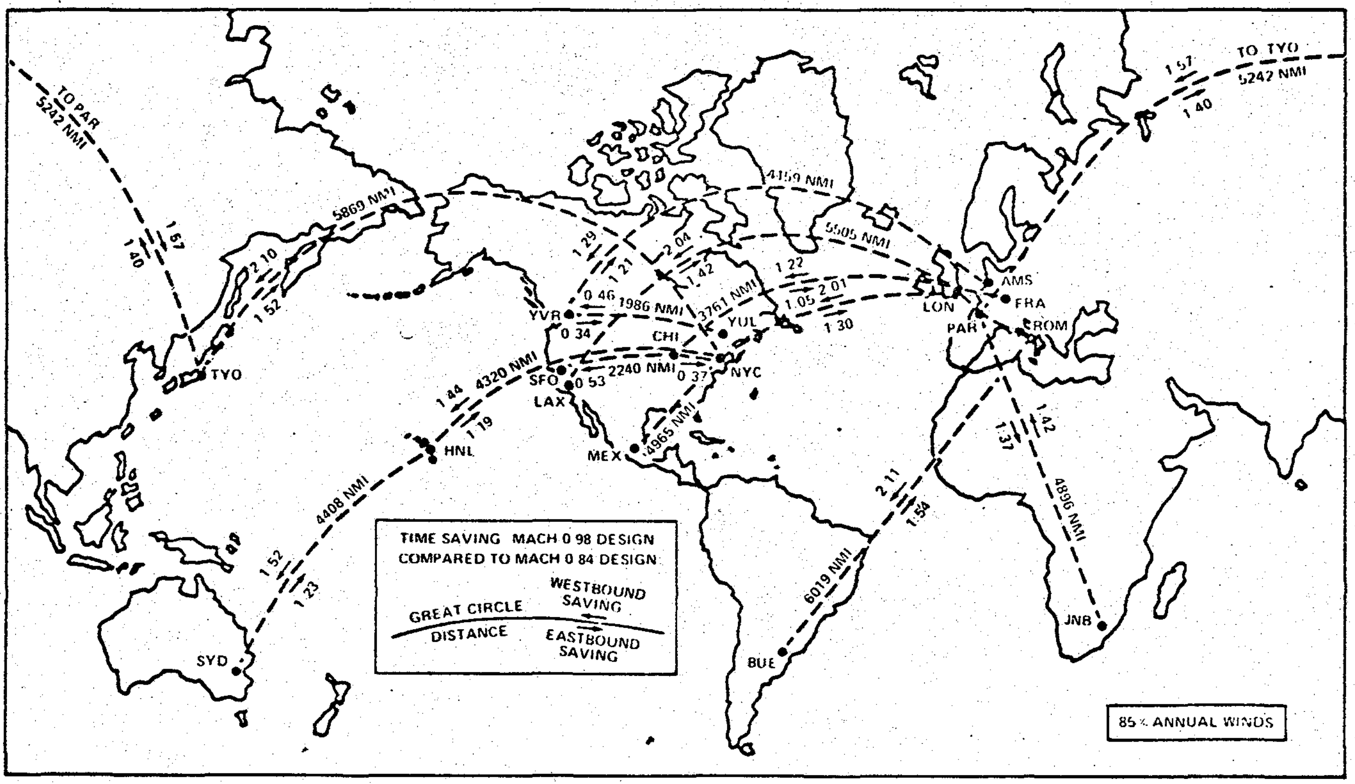


FIGURE 12. TYPICAL AIRLINE ROUTES FOR A MACH 0.98 TRANSPORT

The Mach 0.84 transport incorporates advanced technology to provide significant improvements in economics, community noise, and passenger comfort relative to current jetliners in this market area. The near-sonic transport offers the added advantage of speed. The potential time savings relative to the Mach 0.84 transport are illustrated in Figure 12—up to 2 hours on the longer segments. This design is particularly suited to long, thin routes where passenger and cargo volume are not large enough to require the 747 and also to routes with appreciable overland segments where SST's will not be able to fly supersonically.

The characteristics, performance, and economics of these airplanes are compared in Figure 13. These airplanes have been designed to carry 175 passengers over transcontinental ranges. Wing area and engine size were selected to satisfy selected initial cruise altitude and approach speed requirements. Wing planforms and thickness ratios are compatible with the desired cruise speed. Supercritical airfoil technology has been incorporated on both designs. Engine bypass ratios were chosen on the high side to achieve community noise levels significantly below FAR Part 36 requirements.

The time saving for the Mach 0.98 transport is attained with a 5% increase in direct operating cost. These designs have seat-mile operating costs 15% to 20% lower than the 707-type aircraft.

Major challenges for these configurations include successful application of the supercritical airfoil and the design of a propulsion system for low community noise. The near-sonic airliner includes the additional challenge of transonic aerodynamics, requiring refined area ruling techniques. This is illustrated by the Mach 1.0 area plots in Figure 14. The slenderness ratio must increase with speed to delay drag rise. In addition, particular attention must be given to configuration integration of all components to achieve a smooth area distribution.

CHARACTERISTIC	MACH 0.84	MACH 0.98
GROSS WEIGHT (LB)	244,500	287,300
OEW (LB)	134,650	166,150
THRUST PER ENGINE (LB)	4 AT 19,700	4 AT 27,100
BYPASS RATIO	6:1	5:1
WING AREA (SQ FT)	1920	2300
SWEEP (DEG)	30°	42.5°
ASPECT RATIO	8.5	6.8
TOFL AT SEA LEVEL, 90°F (FT)	6520	6310
APPROACH SPEED (KN)	125	135
INITIAL CRUISE ALTITUDE (FT)	34,000	39,000
RELATIVE DOC	BASE	1.05

FIGURE 13. AIRCRAFT CHARACTERISTICS COMPARISON
(175-Passengers—Transcontinental Range)

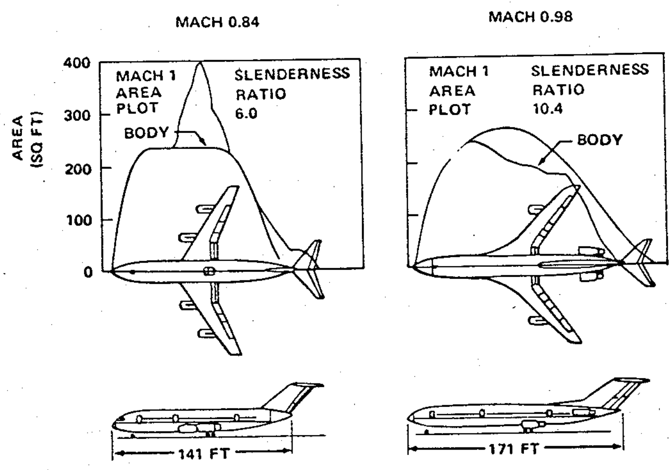


FIGURE 14. AREA PLOT COMPARISON

STOL—Another potential new product opportunity is a short takeoff and landing (STOL) airplane. An artist's sketch of such an airplane is shown in Figure 15. With its short-field performance, it is intended to be able to operate from small airports within or near large cities and thereby avoid the usual long drives to large airports.

Historical data for U.S. intercity auto, bus, and train travel for distances less than 500 miles are compared with air travel in Figure 16. Note that, in 1968, air travel represented less than 1% of auto travel. Only a small diversion of this auto travel to air travel could represent a very large market opportunity for STOL airplanes, in addition to providing some relief to the congestion on freeways.

STOL could, in fact, induce new air travel since the time saving over other modes of transportation could cause more people, especially business people, to take relatively long 1-day trips and avoid overnight stays. Figure 17 illustrates the

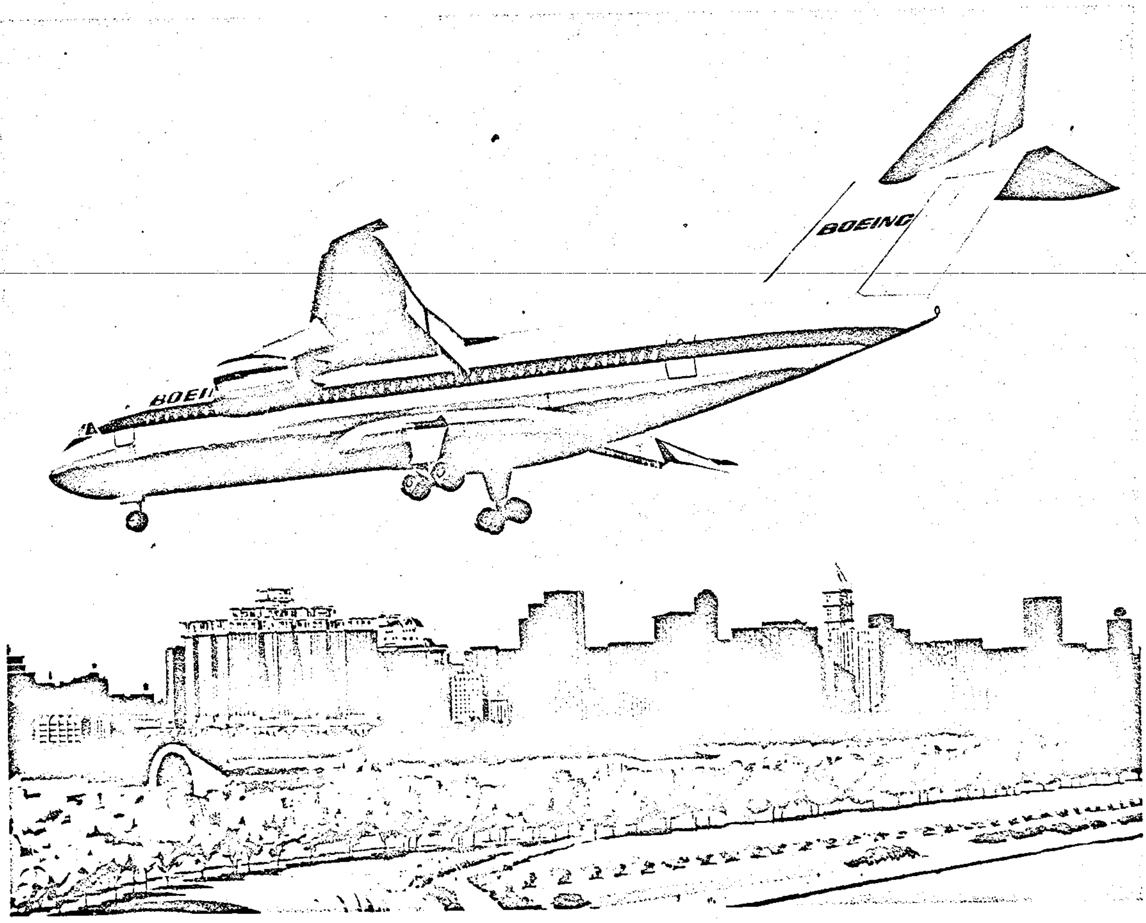


FIGURE 15. STOL CONFIGURATION

total door-to-door travel time required for various modes of travel. The turbofan-powered STOL airplane is superior for distances greater than 100 miles and offers the possibility of round trip travel at distances as far as 400 miles with less than 4 hours total travel time. This time saving can be achieved by providing quicker access to close-in terminals and depends on the use of special navigation equipment so that STOL airplanes can be separated from conventional air traffic. STOL airplanes will operate at speeds as low as 80 knots, so they are not compatible with conventional airplanes in normal traffic patterns. Area navigation and fully programmed takeoffs and landings will be a part of the total system package for successful STOL operation.

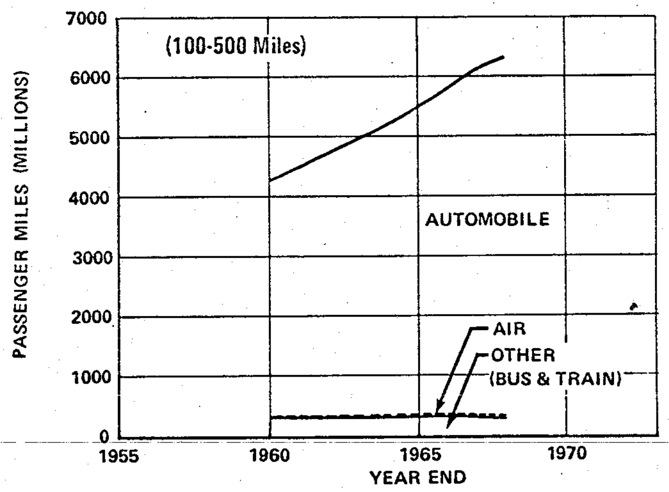


FIGURE 16. SHORT HAUL TRAFFIC DISTRIBUTION

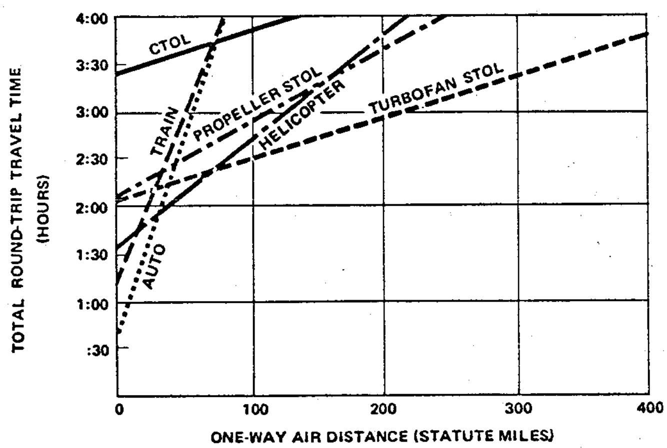


FIGURE 17. ROUND-TRIP TRAVEL TIME COMPARISON

The demand for STOL service is expected to be particularly heavy in the mornings and then again during the evenings, similar to bus and commuter train travel. To improve earning potential, the STOL airplane can be designed with overload capability to operate at longer distances from conventional airports using longer runways when not required for the peak short-haul demand. Such a conventional/STOL concept would allow efficient use of the STOL aircraft throughout the entire day.

Several design concepts for a turbofan STOL configuration are envisioned. Cross-section schematics of possible wing and propulsion system arrangements are illustrated in Figure 18.

The major design challenges for the STOL transport involve development of:

- The high-lift and propulsion systems, which are interactive
- The control system to cope with various failures and adverse wind conditions while depending on engines for augmented lift
- A quiet airplane
- A new flight guidance and control system

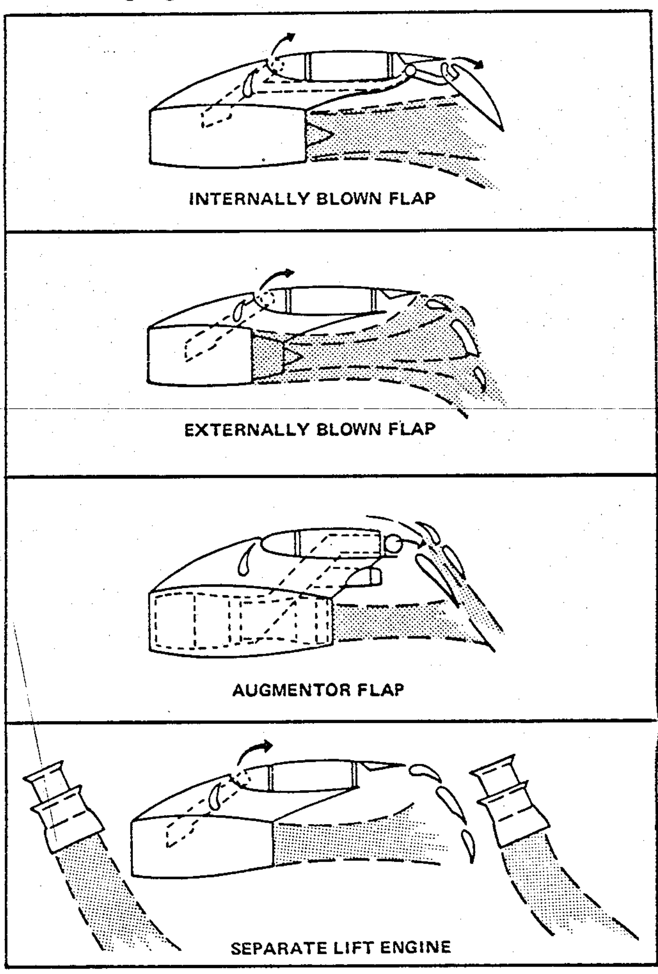


FIGURE 18. TURBOFAN ENGINE—HIGH LIFT WING CONCEPTS

The general characteristics of a STOL aircraft incorporating these features are presented in Figure 19.

Several NASA research hardware programs currently planned or in work will help provide the technical data needed to develop viable STOL configurations. These include

GROSS WEIGHT (LB)	
500 NMI STOL	181,000
1500 NMI CTOL	221,700
OEW (LB)	127,600
THRUST PER ENGINE (LB)	4 AT 24,000
BYPASS RATIO	8.7
WING AREA (SQ FT)	1900
SWEEP (DEG)	25
ASPECT RATIO	7.5
TAKEOFF AT SL/90°F (FT)	
STOL	2000
CTOL	≤4000
APPROACH SPEED (KN)	<80
INITIAL CRUISE ALTITUDE (FT) AT MACH	30,000 AT 0.80

FIGURE 19. STOL AIRCRAFT CHARACTERISTICS (150-Passengers—Internally Blown Flap)

the Buffalo modification, a new experimental research airplane, a demonstrator quiet engine, as well as general STOL research. In addition to these airplane development activities, there is an equivalent air and ground-total systems development requirement involving terminal area and en route traffic guidance and control as well as new terminal facilities with adequate access and egress.

RESOURCE AIR CARRIER—To indicate the degree to which an airplane designer is able to accommodate specific requirements, a brief resume is shown here of a special-purpose resource air carrier. This design is the result of a study to determine whether or not certain natural resources, such as oil or high-value minerals, could be moved from areas of difficult accessibility to transportation points by air.

The general arrangement of such a carrier is presented in Figure 20. In this configuration, the design payload is in excess of 2 million pounds. The gross weight of the airplane is on the order of 3.5 million pounds. The airplane is arranged to carry the payload and the fuel near the lifting surfaces of the wing for an efficient structure. The engines and landing gear are also arranged along the wing for good structural characteristics. The flotation requirements with this extensive landing gear arrangement are equivalent to current-day transports, even with this extremely high gross weight. Low manufacturing costs as well as low maintenance costs were primary factors in arriving at this arrangement. Plan views of the 747 and the resource air carrier can be compared in Figure 21.

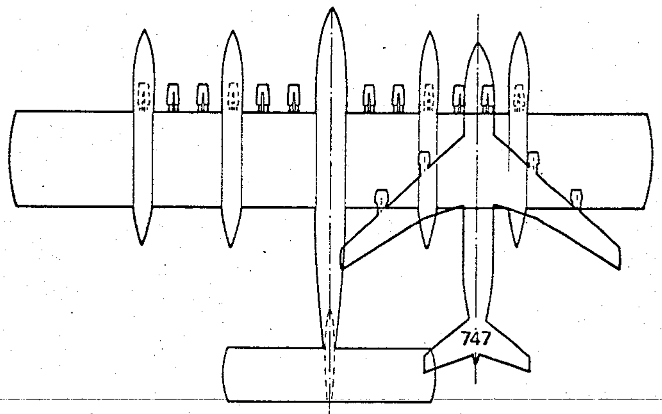
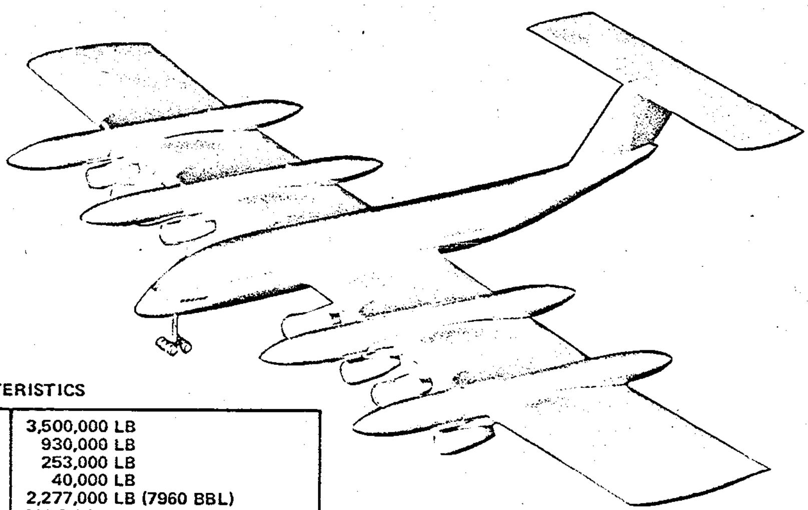


FIGURE 21. PLANFORM COMPARISON, RESOURCE AIR CARRIER AND 747



CHARACTERISTICS

GROSS WEIGHT	3,500,000 LB
OEW + TANKS	930,000 LB
500 NMI FUEL (ROUND TRIP)	253,000 LB
RESERVES	40,000 LB
DELIVERED CRUDE OR SLURRY	2,277,000 LB (7960 BBL)
CRUISE SPEED	MACH 0.65
ENGINES	12 X 55,000 LB SLS TURBOFANS
TIRES	60 MAINS 56 X 24 AT 150 PSI 8 NOSE 56 X 24 AT 150 PSI
WING AREA	29,000 FT^2
WING SPAN	440 FT
TANKS	13 FT DIA X 150 FT LONG

FIGURE 20. RESOURCE AIR CARRIER

CONCLUSIONS

In spite of the difficult period that the aircraft and airline industries are in today, the future market is projected to be large, and additional lift will be required. In the near term, this unfilled lift will be supplied to a considerable extent by current models and derivatives of current models.

Future traffic growth will require new aircraft. Technology advances will allow such features as higher cruising speeds, lower operating costs, short takeoff and landing characteristics, lower community noise, and improved structural life.

Other new special-purpose airplanes will also be required. The resource air carrier is only one example of the many potential opportunities for the application of advanced concepts to air transportation.